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An Investigation Conducted by
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Contract Report

BATTELLE
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REMOVAL OF AQUEOUS PHASE PETROLEUM PRODUCTS IN GROUNDWATER BY AERATION

Abstract This study evaluated the effectiveness of conventional air stripping for removal of jet fuels (JP-5 and AVGAS) from groundwater, using samples collected near the Patuxent River Naval Air Station fuel farm in MD. Using an air flow rate of 0.5 L/min, fuel contaminants (a mixture of JP-5 and AVGAS) were removed in excess of 97% within 30 minutes. At the same flow rate, 96% of a less volatile fuel contaminant (primarily JP-5) was removed in 30 minutes. These results indicate that even low volatility jet fuel can be removed from groundwater to low levels (<2 mg/L) by air stripping. Iron precipitation during aeration of groundwater could plug packed-bed air strippers unless pre-aeration and iron precipitate removal was implemented before packed-bed air stripping.

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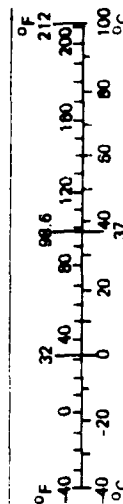
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures				Approximate Conversions from Metric Measures			
Symbol	When You Know	Multiply by	To Find	Symbol	When You Know	Multiply by	To Find
LENGTH				LENGTH			
in	inches	2.5	centimeters	mm	millimeters	0.04	inches
ft	feet	30	centimeters	cm	centimeters	0.4	inches
yd	yards	0.9	meters	m	meters	3.3	feet
mi	miles	1.6	kilometers	km	kilometers	1.1	yards
AREA				AREA			
in ²	square inches	6.5	square centimeters	cm ²	square centimeters	0.16	square inches
ft ²	square feet	0.09	square meters	m ²	square meters	1.2	square yards
yd ²	square yards	0.8	square meters	km ²	square kilometers	0.4	square miles
mi ²	square miles	2.6	square kilometers	ha	hectares (10,000 m ²)	2.5	acres
MASS (weight)				MASS (weight)			
oz	ounces	28	grams	g	grams	0.035	ounces
lb	pounds	0.45	kilograms	kg	kilograms	2.2	pounds
	short tons	0.9	tonnes	t	tonnes (1,000 kg)	1.1	short tons
	(2,000 lb)						
VOLUME				VOLUME			
tsp	teaspoons	5	milliliters	ml	milliliters	0.03	fluid ounces
Tbsp	tablespoons	15	milliliters	l	liters	2.1	pints
fl oz	fluid ounces	30	milliliters	l	liters	1.06	quarts
c	cups	0.24	liters	l	liters	0.26	gallons
pt	pints	0.47	liters	m ³	cubic meters	35	cubic feet
qt	quarts	0.95	liters	m ³	cubic meters	1.3	cubic yards
gal	gallons	3.8	liters				
ft ³	cubic feet	0.03	cubic meters				
yd ³	cubic yards	0.76	cubic meters				
TEMPERATURE (exact)				TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature

*1 in. = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Pub. 286, Units of Weights and Measures, Price \$2.25. SD Catalog No. C13 10 286.



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INTRODUCTION

The objective of this study was to examine air stripping for the removal of hydrocarbons present in two groundwater samples suspected to be contaminated with jet fuels. The groundwater samples were collected at the Patuxent Naval Air Test Center fuel farm and sent to Battelle for the proposed study by the Naval Civil Engineering Laboratory, Port Hueneme, California.

MATERIALS AND METHODS

Two groundwater samples obtained from Wells No. 20 and 25 contained visible layers of fuel floating on the water surface. Water samples as well as the non-aqueous phase liquid (NAPL) floating on the top were analyzed by gas chromatographic methods as described below.

Air Stripping Studies

The experimental set-up for air stripping of water samples is shown in Figure 1. Purified compressed air was used as the source of air for stripping. Approximately 200 mL of water was siphoned into a 250-mL gas washing bottle from the groundwater sample. The test sample did not contain any floating liquid. The water sample was aerated at an air flow of 0.5 Lpm at 10 psig. Aliquots of 2-mL were withdrawn from the reactor at different

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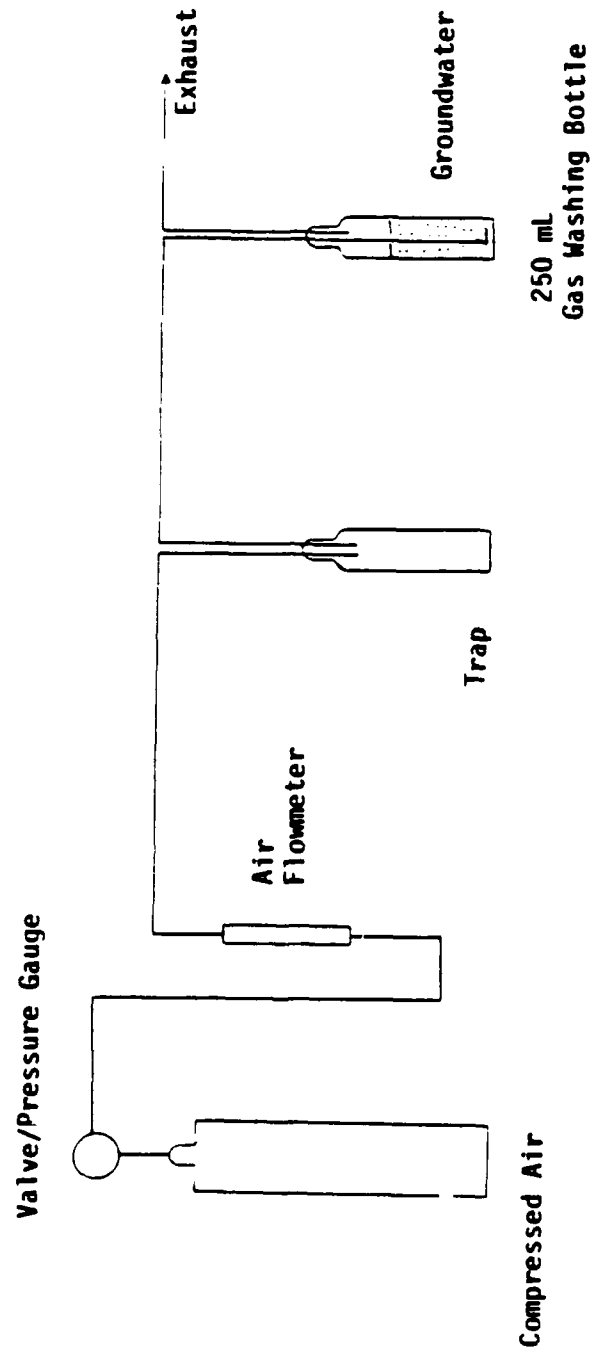


FIGURE 1. SCHEMATIC OF BATCH AERATION UNIT

time intervals and analyzed by gas chromatographic methods described below. Each aeration study was conducted for a period of 1 hr at room temperature.

Analytical Methodology

The qualitative/quantitative analysis of JP-5 in groundwater samples was accomplished using a gas chromatograph (G.C.). The G.C. system included a Varian Model 3700 gas chromatograph equipped with a flame ionization detector (FID) and a Varian Model 4270 integrator.

Organics present in the water samples were chromatographically resolved with the aid of a 6 ft. x 2 mm i.d. 3% OV101 packed column. Optimum analytical results were achieved using a G.C. oven temperature program that holds at an initial temperature of 40°C for 4 minutes then increases to 250°C at 10°/minute. The detector temperature was maintained at 300°C. A 25 ml/minute nitrogen flow was used for the carrier gas. Direct aqueous injections were made of the well water samples. Jet fuel standards were prepared in a methylene chloride matrix using the organics floating on the surface of the groundwater samples as the neat material. A sub-ppm detection limit of hydrocarbon in water was possible with the FID.

RESULTS

A typical chromatogram of the NAPL obtained from Well No. 20 groundwater is shown in Figure 2. This neat injection of the material floating on the surface of the water sample displays a majority of the peaks and total area counts eluting within the first 3 minutes. This would tend to indicate qualitatively that the organics present at Well No. 20 are mainly lower molecular weight (light hydrocarbon) compounds that might be found in the gasoline fraction of jet fuels. Although this organic material is in contact with the well water, it does not presume that all species are actually present or present in similar relative proportion in the aqueous phase.

FIGURE 2. ORGANICS IN CONTACT WITH WATER AT WELL NO. 20.

Figure 2. (continued)

AREA #	AREA	FT	AREA BC
0.000	0.000	0.72	7647 02
0.000	0.000	0.42	1200527 02
0.019	0.50	0.50	71945 02
0.49	0.6	0.6	4274567 02
0.288	0.72	0.72	494003 02
4.891	0.86	0.86	8396742 02
3.15	1.17	1.17	10392762 02
24.988	1.34	1.34	42212008 02
0.027	1.57	1.57	222791 06
0.06	1.77	1.77	15554992 06
21.11	2.11	2.11	19709028 06
0.871	2.27	2.27	15481148 06
0.166	3.11	3.11	284715 06
1.52	4.4	4.4	2610195 06
0.49	4.07	4.07	340549 06
0.487	4.27	4.27	339936 06
0.862	4.84	4.84	4381103 06
1.786	5.51	5.51	1066513 06
1.19	6.67	6.67	1274474 06
0.001	6.97	6.97	1274876 06
0.433	6.68	6.68	1145976 06
0.449	6.88	6.88	420446 06
0.014	7.11	7.11	27373 06
0.017	7.36	7.36	4107157 06
0.014	7.36	7.36	1636097 06
0.014	7.36	7.36	474666 06
0.011	7.11	7.11	319711 06
0.011	7.11	7.11	106394 06
0.011	7.11	7.11	167357 06
1.000	8.03	8.03	1000752 06
0.000	8.46	8.46	344677 06
0.000	8.66	8.66	174226 06
0.000	8.87	8.87	362614 06
0.001	10.07	10.07	87796 06
0.008	10.7	10.7	163714 06
0.019	10.75	10.75	67539 06
0.025	11.03	11.03	278271 06
0.015	11.39	11.39	53746 06
0.012	11.56	11.56	28796 06
0.011	11.9	11.9	53710 06
0.019	12.12	12.12	23049 06
0.008	12.3	12.3	12790 06
0.004	12.46	12.46	73741 06
0.019	12.57	12.57	73717 06
0.046	12.94	12.94	73663 06
0.011	13.11	13.11	73717 06
0.017	13.64	13.64	29712 06
0.012	17.36	17.36	21406 06
0.07	14.16	14.16	52006 06
0.028	14.37	14.37	48774 06
0.017	14.5	14.5	38931 06
0.046	14.75	14.75	77354 06
0.018	15.22	15.22	11293 06
0.029	15.46	15.46	50011 06
0.007	15.92	15.92	12750 06
0.	16.11	16.11	737 07
0.001	17.66	17.66	4490 01
0.001	18.13	18.13	4040 01
0.	19.44	19.44	609 01
0.001	21.34	21.34	367 02
0.001	24.60	24.60	1795 02
0.	24.84	24.84	817 02
0.064	25.46	25.46	109684 01
77761	100.		171620954

Eight of the samples that were collected during the 60 minute air stripping process were analyzed by G.C. and the concentration of organics was calculated based upon the area counts of similar peaks in a jet fuel standard. The results of that analysis for Well No. 20 are presented in Table 1.

Except for sample No. 8, which may have been contaminated, there is apparent reduction of organics over time using air stripping on this water sample.

The analysis of the air-stripped water samples from Well No. 25 was performed in the same manner as previously described. Figure 3 shows a chromatogram for NAPL floating on the surface of the groundwater sample from Well No. 25. This sample shows that NAPL consists of low concentrations of light hydrocarbons and higher levels of the heavy hydrocarbon fractions.

The GC analysis of samples that were collected from Well No. 25 water during the air stripping process is presented in Table 2. A reduction in organic concentration over time is observed when the water sample is air stripped. The problem of apparent sample contamination was again evident with sample No. 10.

DISCUSSION

The results indicate that given the air flow rate utilized most of the hydrocarbons present in aqueous phase can be removed by aeration. When the air flow rate was 0.5 Lpm, the removal of aqueous phase liquid organics from Well No. 20 groundwater exceeded 97 percent within the first 30 min. Similarly, the removal of aqueous phase liquid from Well No. 25 amounted to 96 percent for the same test conditions.

Data presented in the present study indicates that the groundwater examined is typical of fuel contaminated water and clean-up by air stripping following NAPL removal is feasible.

The design configuration of any aeration system must be based upon treatment objectives and other water quality considerations. For example, if low level treatment is required, packed column aeration may be necessary. However, packed column aerators are subject to iron fouling, which could be problematic when treating reduced groundwater.

TABLE 1. CONCENTRATION OF REPRESENTATIVE ORGANICS IN
AIR-STRIPPED GROUNDWATER FROM WELL NO. 20

Sample No.	Duration of Air Stripping (min)	Concentration of Organics (ppm)
1	0.25	6.28
3	1.0	3.54
6	3.0	2.36
8	5.0	5.35
10	10.0	2.05
12	20.0	1.39
13	30.0	0.13
15	60.0	0.02

FIGURE 3. ORGANICS IN CONTACT WITH WATER AT WELL NO. 25.

Figure 3. (continued)

AREA	AREA	ST	AREA
0.001	0.001	0.001	10521 02
0.001	0.001	0.001	10491 02
0.002	0.002	0.002	10142 02
0.002	0.002	0.002	710550 02
0.009	0.009	0.009	211218 02
0.01	0.01	0.01	432591 02
0.018	0.018	0.018	640520 02
0.022	0.022	0.022	714375 02
0.067	0.067	0.067	1756578 02
0.140	0.140	0.140	1564725 02
0.166	0.166	0.166	1023371 02
0.219	0.219	0.219	1745277 02
0.280	0.280	0.280	2236244 02
0.410	0.410	0.410	1330677 02
0.410	0.410	0.410	1011650 02
0.410	0.410	0.410	772207 02
0.410	0.410	0.410	7154457 02
0.410	0.410	0.410	6446447 02
0.410	0.410	0.410	2274111 02
0.410	0.410	0.410	1039125 02
0.410	0.410	0.410	2212754 02
0.410	0.410	0.410	1461657 02
0.410	0.410	0.410	1046258 02
0.410	0.410	0.410	1712445 02
0.410	0.410	0.410	5914006 02
0.410	0.410	0.410	1221397 02
0.410	0.410	0.410	1077596 02
0.410	0.410	0.410	1331579 02
0.410	0.410	0.410	1421955 02
0.410	0.410	0.410	1002321 02
0.410	0.410	0.410	1034155 02
0.410	0.410	0.410	1032115 02
0.410	0.410	0.410	1010775 02
0.410	0.410	0.410	4373300 02
0.410	0.410	0.410	4365011 02
0.410	0.410	0.410	1171552 02
0.410	0.410	0.410	1467622 02
0.410	0.410	0.410	5455170 02
0.410	0.410	0.410	16266991 02
0.410	0.410	0.410	16477997 02
0.410	0.410	0.410	21995276 02
0.410	0.410	0.410	14699701 02
0.410	0.410	0.410	11389457 02
0.410	0.410	0.410	12342322 02
0.410	0.410	0.410	16323922 02
0.410	0.410	0.410	22001796 02
0.410	0.410	0.410	11063398 02
0.410	0.410	0.410	20771511 02
0.410	0.410	0.410	20652290 02
0.410	0.410	0.410	17929544 02
0.410	0.410	0.410	19972271 02
0.410	0.410	0.410	15942255 02
0.410	0.410	0.410	34148307 02
0.410	0.410	0.410	9607646 02
0.410	0.410	0.410	6427997 02
0.410	0.410	0.410	5357321 02
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0.410	0.410	0.410	4757616 02
0.410	0.410	0.410	6136466 02
0.410	0.410	0.410	4178998 02
0.410	0.410	0.410	1073075 02
0.410	0.410	0.410	2400004 02
0.410	0.410	0.410	1214213 02
0.410	0.410	0.410	577699 02
0.410	0.410	0.410	37986 02
0.410	0.410	0.410	161631 02
0.410	0.410	0.410	47574 02
0.410	0.410	0.410	147536 02
0.410	0.410	0.410	16922 02
0.410	0.410	0.410	58251 02
0.410	0.410	0.410	45667 02
0.410	0.410	0.410	21124 02
0.410	0.410	0.410	24197 02
0.410	0.410	0.410	18455 02
0.410	0.410	0.410	15537 02
0.410	0.410	0.410	10308 02
0.410	0.410	0.410	10151 02
0.410	0.410	0.410	14565 02
0.410	0.410	0.410	10324 02
0.410	0.410	0.410	14514 02
0.410	0.410	0.410	11947 02
0.410	0.410	0.410	503119 08
0.410	0.410	0.410	13416 06
0.410	0.410	0.410	5325828 09
0.410	0.410	0.410	470913700

TABLE 2. CONCENTRATION OF REPRESENTATIVE ORGANICS IN
AIR-STRIPPED GROUNDWATER FROM WELL NO. 25

Sample No.	Duration of Air Stripping (min)	Concentration of Organics (ppm)
1	0.25	63.33
3	1.0	16.30
6	3.0	6.75
10	10.0	39.26
11	14.0	3.65
12	20.0	2.80
13	30.0	2.45
15	60.0	1.64

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